METHOD AND APPARATUS FOR ANALYZING PERFORMANCE OF A

MULTI-STAGE RADIO FREQUENCY AMPLIFIER

BACKGROUND OF THE INVENTION

1.Field of the Invention

5   The present is related to a method and an apparatus for analyzing performance of a multi-stage radio frequency amplifier, and especially to a systematic method for rapidly analyzing stage gain and loss of each amplifier.

2. Description of Related Art

Radio frequency amplifiers are important in the design of radio frequency

10   integrate circuits. When circuits are operated under microwave and radio frequencies, circuits with mismatched impedances suffer from decay and loss of power gain.

Fig. 1 shows a prior art single-stage radio frequency amplifier, which comprises an input power source circuit 010, an input-stage matching network

15   030, a single-stage amplifier 050, an output-stage matching network 070 and an output circuit 090. The input power source circuit 010 further includes an input source 012 and an input power source characteristic impedance 014; the impedance value of the input power source characteristic impedance 014 is 50 ohms.

20   The prior art method for analyzing the single-stage radio frequency amplifier is to find a reflection coefficient Γ_S of a power source terminal, a reflection coefficient Γ_L of the load, an input reflection coefficient Γ_{IN}, and an output reflection coefficient Γ_{OUT}. The four coefficients can be adjusted for

acquiring preset gain value.

Matching methods in producing multi-stage radio integrate circuits are important issues in recent years. Prior art methods for analyzing power gain are designed for single-stage radio frequency amplifiers and microwave amplifiers; effective methods for analyzing power loss of multi-stage radio frequency amplifiers have not yet been successfully proposed. A common method applied for analyzing a multi-stage radio frequency amplifier is trial and error, but this wastes time and is ineffective. Prior art circuit simulation methods are hard to use in accounting for the reason why power gain decays.

SUMMARY OF THE INVENTION

The present invention is related to a method and an apparatus for analyzing performance of a multi-stage radio frequency amplifier. The apparatus comprises an input-stage matching network, a mid-stage network, an output-stage matching network and an output circuit. The method mainly includes the following steps: targeting a circuit network for analyzing, and treating non-analyzed circuit networks as mid-stage networks.

Reflection coefficients Γ_S and Γ_L of the targeted circuit network are obtained first, and then a power source matching network maximum gain G_{Smax} and a load matching network maximum gain G_{Lmax} are obtained with a Smith chart. A power source matching network maximum gain G_{SMAX} of the input-stage matching network and a load matching network maximum gain G_{LMAX} of the output-stage matching network can be made by adjusting the reflection coefficients Γ_S and Γ_L.

Circuit networks will be neglected after analysis, and non-analyzed circuit

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networks are decomposed into equivalent circuit parts. One part is targeted for analysis; and the remaining parts are all viewed as a mid-stage network.

Repeating the above-mention steps for analysis will simplify the complexity of the circuit, and the power decays in circuit networks may be found more rapidly.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and many of the attendant advantages of this invention will be more readily appreciated as the same becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

Fig. 1 shows a prior art circuit;

Fig. 2 shows a first embodiment according to the present invention;

Fig. 3 depicts a simplified circuit of the first embodiment according to the present invention;

Fig. 4A shows a device for obtaining a reflection coefficient Γ_S of a power source;

Fig. 4B shows a device for obtaining a reflection coefficient Γ_L of a load;

Fig. 5A shows another simplified circuit of the first embodiment according to the present invention;

Fig. 5B shows another simplified circuit of the first embodiment according to the present invention for obtaining a reflection coefficient Γ_S of a power source;

Fig. 5C shows another simplified circuit of the first embodiment according

to the present invention for obtaining a reflection coefficient Γ_L of a load;

Fig. 6 shows a second embodiment according to the present invention; and

Fig. 7 shows a flow chart of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

5   The object of the present invention is to provide a method and an apparatus for analyzing a multi-stage radio frequency amplifier, and finding decay in the multi-stage radio frequency amplifier.

Fig. 2 shows a first embodiment of the present invention. The multi-stage radio frequency amplifier of the present invention includes an input power source circuit 100, an input-stage matching network 110, a first-stage amplifier

10   source circuit 100, an input-stage matching network 110, a first-stage amplifier 120, a mid matching network 130, a second-stage amplifier 140, an output-stage matching network 150, and an output circuit 160 (may be an impedance with 50 ohms). The input power source circuit 100 comprises a power generating device 102 and an input characteristic impedance 104 (usual

15   value of the impedance is 50 ohms). The mid matching network 130 is provided between a first-stage amplifier 120 and a second-stage amplifier 140.

Reference is made to Fig. 3. The above-mentioned first-stage amplifier 120, the second-stage amplifier 140 and the mid matching network 130 are combined into a mid-stage amplifier 135; therefore, the complexity of amplifier

20   analysis can be simplified. A reflection coefficient Γ_S of the input-stage matching network 110 and a loading reflection coefficient Γ_L of the output-stage matching network 150 will be obtained; the reflection coefficient Γ_S of the input-stage matching network 110 is then adjusted to be $\Gamma_{S,max}$ for conjugate matching with an input reflection coefficient Γ_{IN} of the mid-stage

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amplifier 135. The loading reflection coefficient Γ_L of output-stage matching network 150 is adjusted to be $\Gamma_{L,max}$ for conjugate matching with an output reflection coefficient Γ_{OUT} of the mid-stage matching network.

Two formulas are provided for obtaining a power source gain G_S of input-stage matching network and loading gain G_L. Reflection coefficient Γ_S, the reflection coefficient Γ_L, the input reflection coefficient Γ_{IN}, and the output reflection coefficient Γ_{OUT} are used as parameters.

$$Gs = \frac{1-\left|\Gamma_s\right|^2}{\left|1-\Gamma_s\Gamma_{IN}\right|^2} \qquad\qquad G_L = \frac{1-\left|\Gamma_L\right|^2}{\left|1-\Gamma_{OUT}\Gamma_L\right|^2}$$

A power source maximum gain G_{Smax} and a loading maximum gain G_{Lmax} can be obtained by adjusting the reflection coefficient Γ_S and the reflection coefficient Γ_L; a power circle of a Smith chart will show the value of G_{Smax} and G_{Lmax}. Thus, the best power transferring rate and lowest gain loss will be made. Further, the difference between the power source gain G_S and the power source maximum gain G_{Smax} is the loss of power gain due to unmatched input-stage impedance; and the difference between loading gain G_L and loading maximum gain G_{Lmax} is loss of power gain due to unmatched output-stage impedance.

Reference is made to Fig. 4A, it shows the method for obtaining the above-mentioned reflection coefficient Γ_S of the input-stage matching network 110, wherein an input characteristic impedance 300 and an output characteristic impedance 310 are both 50 ohms. Incident wave intensity and reflection wave intensity may be measured at first, and the reflection coefficient Γ_S of the power source will be gained by calculating the ratio of them.

Reference is made to Fig. 4B, which shows the method for obtaining the

above-mentioned reflection coefficient Γ_L of the output-stage matching network 150. An input characteristic impedance 300 and an output characteristic impedance 310 are both given as 50 ohms. Incident wave intensity and reflection wave intensity may be measured at first, and the reflection coefficient Γ_L of the power source will be gained by calculating the ratio thereof.

Reference is made to Fig. 5A; after analyzing Fig. 2, the mid-stage amplifier is restored to the original first-stage amplifier 120, the mid matching network 130, and the second-stage amplifier 140. The matched input-stage matching network 110 and the matched output-stage matching network 150 are neglected. This method is undisclosed in prior art method for analyzing radio frequency and microwave amplifiers.

Gain of the first-stage amplifier 120 is a fixed value G_{01} (gain S_{21} (dB) is measured when impedances at two terminals are both 50 ohms, where S_{21} is the ratio of output power and input power); and gain of the second stage amplifier 140 is a fixed value G_{02} (gain S_{21} (dB) is measured when impedances at two terminals are both 50 ohms). Because the mid matching network 130, the second-stage amplifier 140 and the output circuit 160 can be viewed as an output load of the first-stage amplifier, the reflection coefficient Γ_L of the load is obtained by the method shown in Fig. 5C. Similarly, the mid matching network 130, the first-stage amplifier 120 and the output circuit 100 can be treated as an input load of the second-stage amplifier, and the reflection coefficient Γ_S of the power source is obtained by the method shown in Fig. 5B. Thus, the corresponding load matching network gain G_L and the power source

matching network gain G_S can be obtained by applying above-mentioned two methods.

A power source maximum gain G_{Smax} and a loading maximum gain G_{Lmax} can be obtained by adjusting the power source reflection coefficient Γ_S of the mid matching network of the second-stage amplifier and the loading reflection coefficient Γ_L of the mid matching network of first-stage amplifier; an optimal gain may be acquired by Smith chart. The difference between the power source gain G_S and the power source maximum gain G_{Smax} is the loss of power gain due to the first-stage amplifier 120 being unmatched by mid matching network 130; and the difference between loading gain G_L and loading maximum gain G_{Lmax} is loss of power gain due to the second-stage amplifier 140 being unmatched with the mid matching network 130. So, adjusting the mid matching network 130 can obtain the maximum gain and least loss.

Reference is made to Fig. 6, which shows another embodiment of the present invention where the circuit may be analyzed by using the methods provided in Fig. 4A, Fig. 4B, Fig. 5B, Fig. 5C. An input power source circuit 500 depicted in Fig. 6 includes a power generating device 502, and an input characteristic impedance 504. An input-stage matching network 510 is connected to the input power source circuit 500 and the first-stage amplifier 520, a first stage amplifier 520 is connected behind the input-stage matching network 510, and a first-stage mid matching network 530 is set between the first-stage amplifier 520 and the second-stage amplifier 540. Each stage amplifier is therefore connected one by one and there is a corresponding mid-stage matching network set between every two stage amplifiers. Finally,

an Nth stage amplifier is connected to an output-stage matching network 580 and an output circuit 590. The output circuit 590 may have a characteristic impedance (50 ohms).

In this embodiment according to the present invention, gain (G_{01}, G_{02}, G_{03}, to G_N) of each stage amplifier is analyzed with scattering parameters and uses an impedance of 50 ohms. The reflection coefficients Γ_S of the power source terminal of the mid-stage matching network and of each stage amplifier, as well as a reflection coefficient Γ_L of a load, are obtained in sequence by the above-mentioned methods.

Additionally, the first-stage amplifier 520, the first-stage mid matching network 530, the second-stage amplifier 540, a N-1$_{th}$ stage amplifier 550, a N-1$_{th}$ stage mid matching network 560 and a N$_{th}$ amplifier 570 are all treated as an N$_{th}$ stage mid stage amplifier. Then, a reflection coefficient Γ_S of a power source of the input-stage matching network 510 is adjusted to be $\Gamma_{S,max}$ for conjugate matching with an input reflection coefficient Γ_{IN} of the first stage amplifier 520 and a loading reflection coefficient Γ_L of an output-stage matching network 580 is adjusted to be $\Gamma_{L,max}$ for conjugate matching with an output reflection coefficient Γ_{OUT} of the N$_{th}$ amplifier 570. The maximum gain G_{Smax} of the input-stage matching network 510 and the maximum gain G_{Lmax} of output-stage matching network 580 can be obtained with a Smith chart.

After the maximum gain G_{Smax} of the input-stage matching network 510 and the maximum gain G_{Lmax} of output-stage matching network 580 are acquired, the above two matching network will be neglected. Next, the

first-stage amplifier 520, the first-stage mid matching network 530, the second-stage amplifier 540, the $(N-1)_{th}$-stage amplifier 550, the $(N-1)_{th}$-stage mid matching network 560 and the N_{th}-stage amplifier 570 will be analyzed. The first-stage mid matching network 530, the second-stage amplifier 540, the

5    $(N-1)_{th}$-stage amplifier 550, and the $(N-1)_{th}$-stage mid matching network 560 are again viewed as a mid multi-stage amplifier. A loading reflection coefficient Γ_L' of the first-stage mid matching network 530 is obtained by regarding the mid multi-stage amplifier as a load of the first-stage amplifier. The power source reflection coefficient Γ_S' of the $(N-1)_{th}$-stage mid matching

10   network 560 is obtained by regarding the mid multi-stage amplifier as an input network of the N_{th}-stage amplifier. By adjusting a reflection coefficient Γ_S' of a power source of the $(N-1)_{th}$ stage mid matching network to be $\Gamma_S'_{max}$ for conjugate matching with an input reflection coefficient Γ_{IN} of the N_{th} stage amplifier 570 and adjusting a loading reflection coefficient Γ_L' to be $\Gamma_L'_{max}$ for

15   conjugate matching with an output reflection coefficient Γ_{OUT} of the first amplifier 520, the input maximum gain $G_{S'max}$ of the N_{th}-stage amplifier 570 and the loading maximum gain $G_{L'max}$ of the first-stage matching network 520 can be obtained with a Smith chart.

To simplify the complexity of circuit analysis, the first-stage amplifier 520

20   and the N_{th} stage amplifier 570 are neglected. the remaining part of the circuit is decomposed into a first-stage mid matching network, a multi-stage amplifier (including the second-stage amplifier 540, the $(N-1)_{th}$-stage amplifier 550 and other stage circuits, which are not shown) and a $(N-1)_{th}$-stage mid matching network.

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A loading reflection coefficient Γ_L'' is obtained by regarding the $(N-1)_{th}$-stage mid matching network 560 as a load, and the input reflection coefficient Γ_S'' is obtained by regarding the first-stage mid matching network 530 as an input network of the N_{th}-stage amplifier. The reflection coefficient Γ_S'' is adjusted to be $\Gamma_{S}''_{max}$ for conjugate matching with an input reflection coefficient Γ_{IN} of the second stage amplifier 540 and the loading reflection coefficient Γ_L'' to be $\Gamma_{L}''_{max}$ for conjugate matching with an output reflection coefficient Γ_{OUT} of the $(N-1)_{th}$-stage amplifier 550. The input maximum gain $G_{S'max}$ of the second stage amplifier 540 and the loading maximum gain $G_{L'max}$ of the $(N-1)_{th}$-stage amplifier 550 can be obtained with a Smith chart.

Following the procedure described in conjunction with Fig. 4A, Fig. 4B, Fig. 5B, and Fig. 5C, analysis of the power gain and loss in mid matching network of each amplifier can be completed. At last, a maximum transducer power gain $G_{T,MAX}$ is made by adjusting the Γ_S and Γ_L of each matching network. Hence, using the above-mentioned methods can speed up the design of a circuit and find the reason why the gain of the circuit decays easily.

Fig. 7 shows the flow chart of the present invention. A first step S700 is to identify whether the type of an external network of a multi-stage radio frequency amplifier is a matching stage network or amplifier stage network. Next step S701 simplifies the multi-stage radio frequency amplifier into a front-stage matching network, mid-stage amplifier, and a back-stage matching network if the external network is a matching network. If the external network is an amplifier network, the multi-stage radio frequency amplifier is simplified into a front-stage amplifier, mid-stage matching network, and a

back-stage amplifier.

When the multi-stage radio frequency amplifier is simplified into the front-stage matching network, the mid-stage amplifier, and the back-stage matching network, a step S703 will analyze the simplified multi-stage radio frequency amplifier and a load reflection coefficient Γ_L of the back stage matching network is obtained by the method shown in Fig. 4B. A power source reflection coefficient Γ_S of the front-stage matching network is obtained by the method shown in Fig. 4A. Next, the reflection coefficient Γ_S is adjusted to be $\Gamma_{S,max}$ for conjugate matching with an input reflection coefficient Γ_{IN} of the mid stage amplifier and the load reflection coefficient Γ_L of an back-stage matching network is adjusted to be $\Gamma_{L,max}$ for conjugate matching with an output reflection coefficient Γ_{OUT} of the mid stage amplifier. The input maximum gain G_{Smax} of the input-stage matching network and the loading maximum gain G_{Lmax} of the output-stage matching network can be obtained by analyzing a power circle of a Smith chart.

When the multi-stage radio frequency amplifier is simplified into the front-stage amplifier, the mid-stage matching network, and the back-stage amplifier, the step S703 will analyze the simplified multi-stage radio frequency amplifier and a load reflection coefficient Γ_L of the front-stage matching network is obtained by the method shown in Fig. 5C (the mid-stage matching network and the back-stage amplifier are viewed as a load for the front-stage amplifier). A power source reflection coefficient Γ_S of the back-stage matching network is obtained by the method shown in Fig. 5B (the mid-stage matching network, and the front-stage amplifier are viewed as an power input

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network for the back-stage amplifier). Next, the input maximum gain G_{Smax} of the back-stage matching network and the loading maximum gain G_{Lmax} of the front-stage matching network will be made by regulating the mid-stage matching network.

5   After step S705, a step S707 is performed for judging whether all circuits have been analyzed or not. If yes, then the procedure is complete and all the circuit networks can make the input maximum gain G_{Smax} and the loading maximum gain G_{Lmax}; the multi-stage radio frequency amplifier can also make a maximum transducer power gain $G_{T,MAX}$. If not, the procedure will return to

10   the step S700 for analyzing unset circuits, and all above-mentioned methods are executed again until all circuits are set.